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ACOUSTIC CHARACTERISTICS OF SNOW LAYER (SEKISETSU NO ONKYO TOKU--ETC(U)
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ACOUSTIC CHARACTERISTICS OF A SNOW LAYER

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COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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SNOW LAYER

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Using white noise, the transmission loss of fallen snow samples was measured. The attenuation coefficient of sound within fallen snow was measured from this. In addition, the sound sites of a level, fresh snow surface and of a compact snow tunnel and snow trench were studied and the attenuation coefficients at these snow surfaces were found. The frequency characteristics of the attenuation coefficient of a fallen snow sample and a snow surface had the same tendencies as the sound absorption characteristics of the samples. In

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cont. addition, ~~we found that~~ the attenuation at a fresh snow surface was about 1/100 that of the attenuation within a sample of compact snow. ~~We believe~~ these samples will serve as references for acoustic design in snow regions and the TL characteristics of fallen snow samples have a close relation to the structure. ~~We anticipate that~~ this will serve as an indicator of the structure of fallen snow.

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I. INTRODUCTION

The first sound characteristic of snow which is noticed is the fact that sound absorption is good. The density of fallen snow ranges from 0.1 to 0.5 for transition from fresh snow to compact snow. In other words, the air volume included in the unit volume of fallen snow depends on the porosity of snow which ranges from 89% to 44%. There have been numerous reports [1 - 5] on the rate of sound absorption of snow but this report concerns measurement of the degree of attenuation after the majority of the projected sound energy has permeated the fallen snow. The difference between fallen snow and general sound material is that while composed solely of ice, it is very diverse in structure. For example, even in snow of the same density, the sound characteristics will differ greatly depending on the shape and size of the snow grains or on the differences in structures of the snow bridges in which the snow grains are connected. However, since the sound attenuation within fallen snow is determined primarily by the thermal conduction of air within the snow and by the viscosity rather than by the vibration of the snow itself, the effect of temperature is slight. If we assume that the attenuation characteristics vary with temperature change, the structure within the snow due to temperature change will change with sublimation transformation etc., a secondary effect. The measurement was carried out at outdoor temperatures of -5° to -15°C. Experiments were conducted with attention to differences in air flow resistance rather than differences in snow characteristics, specifically classifications due to density.

II. TRANSMISSION LOSS OF SNOW LAYER

Transmission loss* (usually abbreviated TL) is used to express the degree of sound insulation of a material quantitatively. The definition is as follows:

$$TL = 10 \log_{10} \frac{\text{projected sound}}{\text{transmitted sound}} (\text{db}) \qquad (1)$$

*Hokkaido University Low Temperature Science Laboratory Results, No. 660. Low Temperature Science, Physical Ed., No. 22, 1964.

However, it is difficult to directly measure the intensity of projected sound and the intensity of transmitted sound. The following method is used in measurement of TL of a snow layer.

A hole one meter wide was dug to the ground surface in snow approximately 1.5 meters deep and a square hole was opened virtually in the middle of the perpendicular section of the wall of the snow. The depth of the hole was 85 cm, while the sides measured 60 and 40 cm. The anterior surface of this hole was covered with a block of snow 23 cm thick so that a hole within the snow measuring 62 x 60 x 40 cm was formed which was used as a sound chamber. The sound source was a 20 cm diameter moving coil loudspeaker fitted in a closed spherical container of 40 cm diameter. This was fitted in the sound chamber and after confirmation of no sound leakage, a square opening 15 x 15 cm was made in the center of the snow block cover in the front of the sound chamber for the passage of sound. In order to install the snow layer sample in this front, a 25 cm square cavity 5 cm thick was made in the cover. Figure 1 shows the sectional figure of this sound chamber viewed from above. The snow from the surface to a depth of more than 20 cm was virtually uniformly compact snow with a density of 0.3 - 0.4. The sheet-like sample 25 x 25 cm used a horizontal layer of fallen snow with a uniform structure and the thickness varied from 2 cm to 10 cm. Accordingly, the TL of the snow used here was with sound transmitted up and down in the snow and, from the structure of the sound room, the sound was projected virtually perpendicularly in the sample. The temperature during measurements was the outdoor temperature of -7°C. The intensity of the sound was measured for the C characteristic of a noise meter by means of a small crystal microphone. The intensity of the projected sound was measured at the surface of the sample on the side of the sound room, while the intensity of the transmitted sound was measured at the surface outside of the sample. There was a snow wall one meter away from the outside of the sample and since the top was opened to the outside, there was virtually no reverberation. If the level of the intensity of the sound on the projection side is taken as L_1 and if the level of the intensity of sound on the transmission side is taken as L_2, TL is found from

$$TL = L_1 - L_2 \qquad (2)$$

The sound source uses white noise with the frequency characteristics indicated in Figure 2, while the level of the noise intensity is measured at all ranges passing through a 1/3 octave band bass filter with the characteristics shown in Figure 3, or 100 - 800 c/s is divided into 20 frequency bands and measurement is conducted with an indicator noise meter.

Figure 4 shows the TL frequency characteristics of compact snow with density of 0.35 and air flow resistance of 14.0 g/s·cm^3. In the figure, the TL in the vicinity of 2-00 c/s diminishes, but since this tendency is also seen in other snow samples, it is believed to be an error due to the measurement apparatus and not something indicated by some characteristic of the fallen snow. The entire TL of white noise is 10.5 db when the thickness of the compact snow is 2 cm, is 12.5 db when the thickness of the snow is 4 cm, and is 15.5 db when

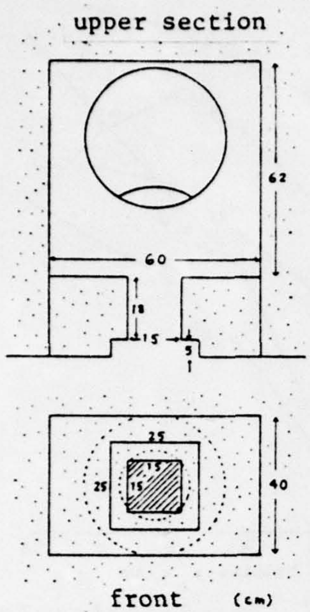

Figure 1. Device for measurement of transmission loss of snow sample.

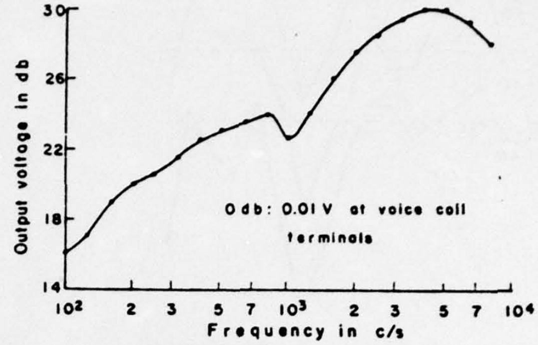

Figure 2. Frequency characteristics of the white noise used as sound source.

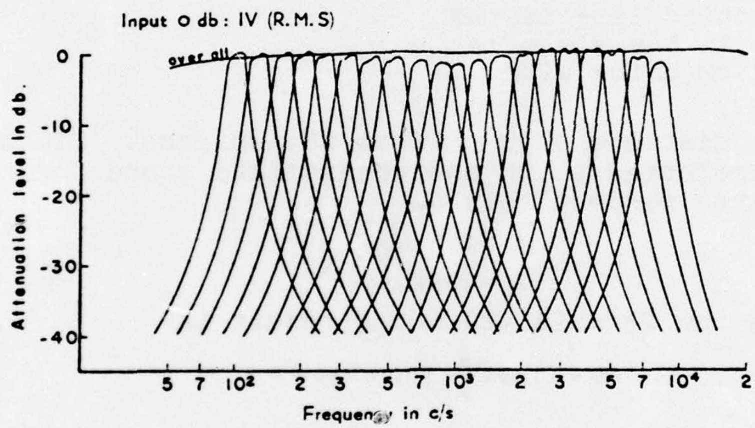

Figure 3. Characteristics of band bass filter.

the thickness is six cm. For comparison, the TL [6] of a pumice block in the air 10.2 cm thick with two holes in it is indicated in the figure by a dotted line. Similar tendencies are indicated in the case of porous material such as pure felt 10 cm thick. The TL increases as the frequency rises. In contrast to this, the TL frequency characteristics of fallen snow may be considered as even, but at each frequency, it is characteristic for considerable unevenness to occur. Figure 5 shows the change in TL in relation to thickness at different frequencies for compact snow of 0.35 density, 19.8 g/s·cm^3 air flow resistance.

If the intensity of the sound in the snow layer was to diminish logarithmically with transmission distance, the sound pressure p_0 at the surface would be

$$p = p_0 e^{-az} \qquad (3)$$

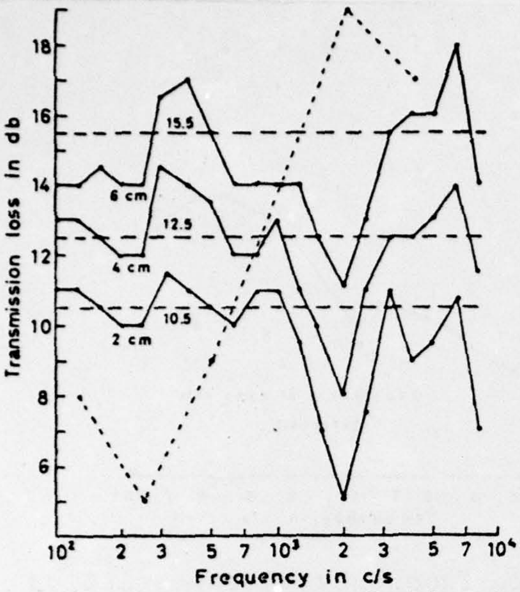

Figure 4. Transmission loss of compact snow (density 0.35, air flow resistance 14.0 g/s·cm^3). The horizontal broken lines are the entire characteristics of white noise while the dotted line is the transmission loss in the air of a pumice block 10.2 cm thick with two holes.

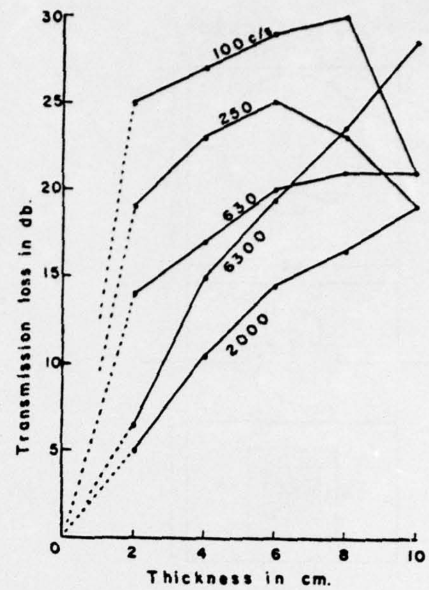

Figure 5. Transmission loss of compact snow (density 0.35, air flow resistance 19.8 g/s·cm^3).

at a transmission distance of x cm from the surface. If the levels of intensity of projected sound and transmitted sound during measurement of TL are taken respectively as

$$L_1 = 20 \log_{10} p_0 \tag{4}$$
$$L_2 = 20 \log_{10} p,$$

substituting this for formula (2) would result in

$$TL = 20 \log_{10} \frac{p_0}{p} = (20\,\alpha \log_{10} e)\,x \tag{5}$$

TL is proportionate to x. However, as shown in Figure 5, it is not a straight line in relation to thickness. Especially when the frequency is low, the TL is maximum at a certain thickness. This is probably because with thick samples, the TL declines since resonance develops. Since TL changes in Figure 5 in a fairly linear manner up to thicknesses of 2-6 cm, the attenuation coefficient α in snow calculated from that inclination will appear as shown in Figure 6. Scott measured the attenuation coefficient directly by inserting a probe tube microphone in a sample of porous rock wool (Stillite, bulk density 0.080 g/cm^2). That value is the dotted line in Figure 6. In the case of fallen snow, when a probe tube is inserted, direct measurement ofthe attenuation coefficient is difficult because the structure will have been destroyed. Figure 6 is the result of indirect measurement, but it indicates that compact snow has the same type of attenuation coefficient frequency characteristics as those of porous sound-absorbent material.

How does the TL change with differences in snow? Figure 7 is a plot of the TL of the entire range of white noise versus the thickness

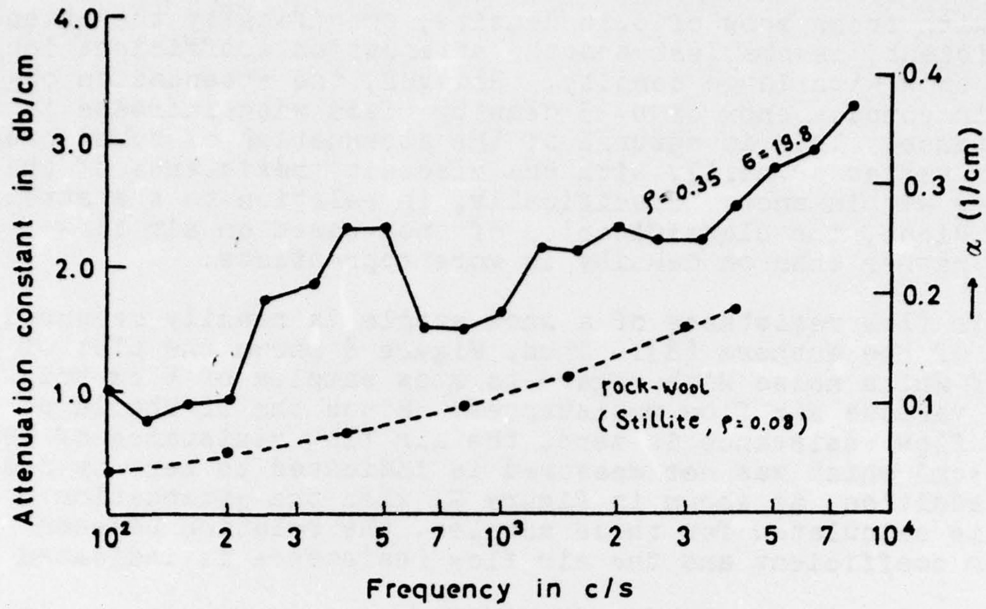

Figure 6. Attenuation coefficient of compact snow (0.35 density, air flow resistance 19.8 g/s·cm³). Dotted line is rock-wool (Stillite).

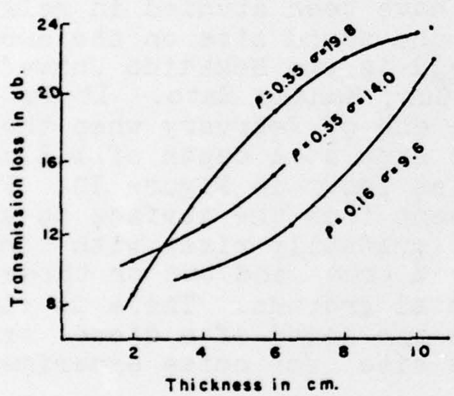

Figure 7. Transmission loss of the entire range of white noise versus three types of snow sample.

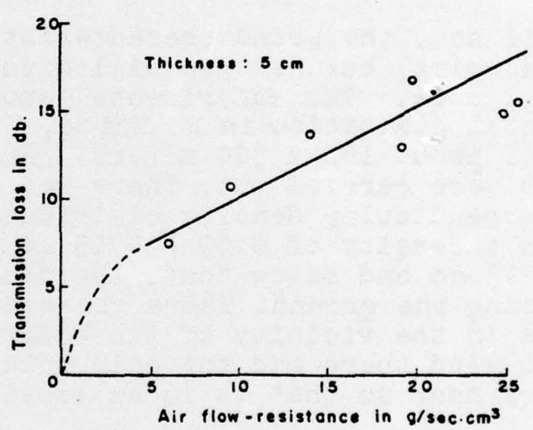

Figure 8. Relation between air flow resistance and transmission loss of snow sample of 5 cm thickness.

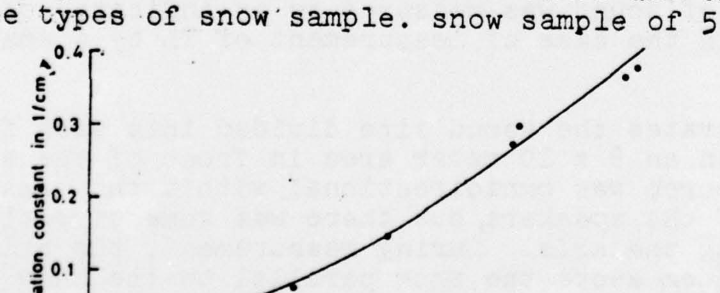

Figure 9. Relation between air flow resistance of fallen snow and attenuation coefficient.

of three types of snow samples. The inclination of TL to thickness with fresh snow of 0.16 density, specifically the attenuation coefficient, is smallest and the attenuation coefficient increases in compact snow with large density. However, the attenuation coefficient in compact snow of 0.35 density rises with increase in air flow resistance. This is natural if the attenuation of sound pressure within snow varies primarily with the viscosity resistance of the air of the pores within snow. Specifically, in relation to the attenuation coefficient, the classification of snow based on air flow resistance rather than on density is more appropriate.

The air flow resistance of a snow sample is readily measured by the method of the authors [8]. Thus, Figure 8 shows the plot of the total TL of white noise with regard to snow samples of 5 cm thickness which have various air flow resistances. Since the TL should be zero if the air flow resistance is zero, the air flow resistance of less than 5 $g/s \cdot cm^3$ which was not measured is indicated to zero by a dotted line. In addition, as shown in Figure 9, when the attenuation coefficient is calculated for these samples, the relation between the attenuation coefficient and the air flow resistance is indicated by

$$\alpha\,(1/\mathrm{cm}) = 0.003\,\sigma + 0.00052\,\sigma^2 \qquad (6)$$

III. SOUND SITE ABOVE THE SNOW

Until now, the sound characteristics have been studied in relation to snow samples, but next we will discuss the sound site on the surface of natural snow. The experimental snowfield is the Hokkaido University experimental plantation in Hokkaido, Uryu Gun, Hahako Sato. It is an area of about 100 x 300 meters. At the end of February when the experiments were carried out, there was even snow at a depth of 1.5 meters with a perpendicular density distribution as shown in Figure 10. Fresh snow with a density of 0.09 - 0.15 is present from the surface to a depth of 15 cm and below that, the density gradually rises with compact snow forming the ground. There are scattered trees and two or three buildings in the vicinity of the experimental grounds. There is virtually no wind there and the only noise is the sound of a diesel train horn every hour so that it is an excellent site for noise experiments.

White noise was used as the sound source by means of a speaker in a closed spherical container as stated in the section on transmission loss. The intensity of sound was measured by an indicator octave band bass filter just as in the case of measurement of TL by a small crystal microphone.

Figure 11 illustrates the sound site divided into each frequency band above the snow in an 8 x 10 meter area in front of the sound source. The sound source was omnidirectional within the area at right angles to the axis of the speakers, but there was some directivity within the area comprising the axis. During measurement, the axis of the speaker was placed 35 cm above the snow parallel to the snow surface. When viewed from above with the sound source as the center, the first quadrant and the second quadrant of the sound site were completely symmetrical so that only the sound site of the

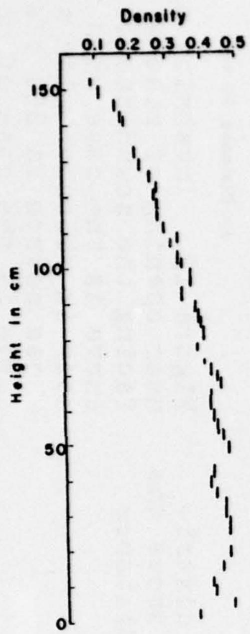

Figure 10. Perpendicular density distribution of snow in experiment.

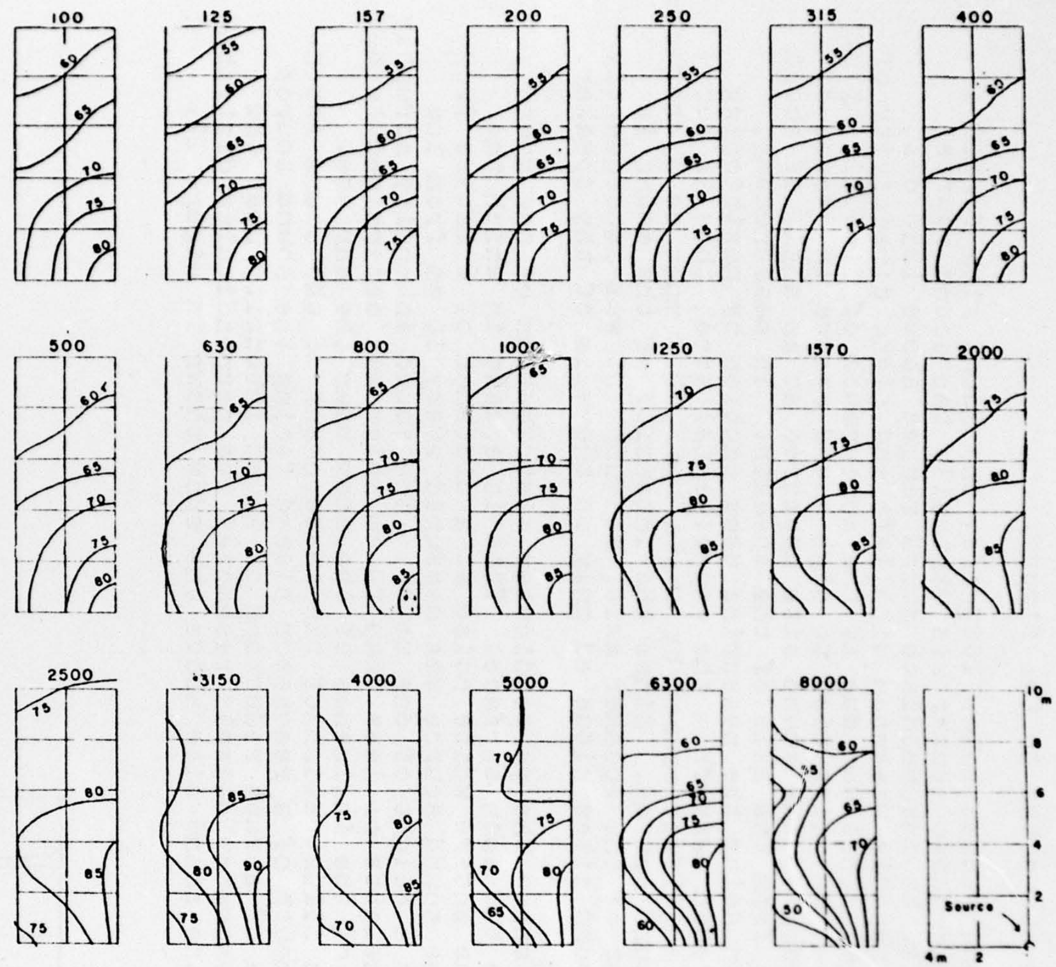

Figure 11. Sound site above the snow. The numbers above each block are the frequencies. Numbers above each height contour indicate intensity levels of sound.

second quadrant was noted in the figure.

At low sound ranges below 1000 c/s, the sound site formed a concentric circle whose center was virtually the sound source, but with the rise to intermediate sound ranges above 1250 c/s, the sound site rapidly weakened with left and right directivity of the sound source. This was due to the appearance of directivity of the sound source, but with rise to high sound ranges in excess of 3150 c/s, disorder of the sound site appeared at an angle of about 27° to the left from the axis of the speaker. In measurement, since the person doing the measuring uses caution by positioning himself in a trench away from the experimental site, this is not believed to be an effect caused by obstacles. This must be a characteristic of the sound source. Since the intensity of the sound is uniform in front of the speaker axis, measurement was subsequently conducted of sound sites situated only on the axis of the speaker.

Figure 12 shows the perpendicular distribution of the sound intensity above the snow surface. This is a case in which the intensity of the entire white noise at a distance of 6 meters from the front of the sound source was measured every 10 cm from the snow surface to a height of one meter. The sound intensity abruptly diminished at heights of less than 20 cm which was determined to be the appearance of the influence of the snow near the surface. Figure 13 is an illustration of the measurement of the sound intensity near the mouth of a resonator placed facing the sound source [9]. The curve of abrupt reduction of sound intensity near the mouth of the resonator closely resembles the perpendicular distribution curve of the sound site above the snow shown in Figure 12.

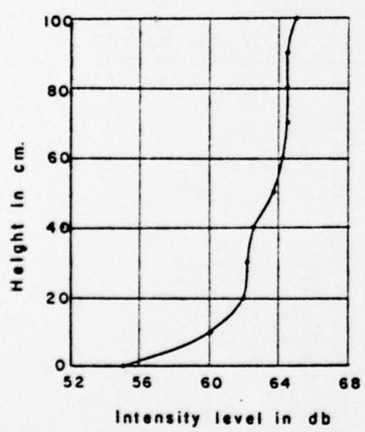

Figure 12. Perpendicular distribution of sound intensity above the snow surface.. Six meter distance from sound source.

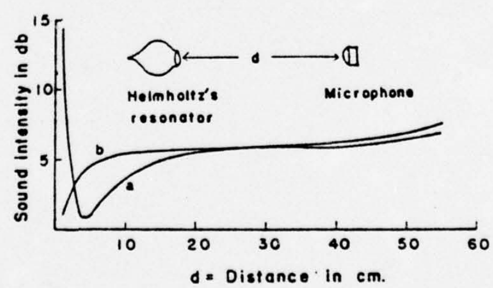

Figure 13. Intensity of sound near opening of resonator placed facing the sound source. The a curve is the case when the resonator is resonant with a sound whose source is 250 c/s. The b curve is the case of no resonance (K. Sato).

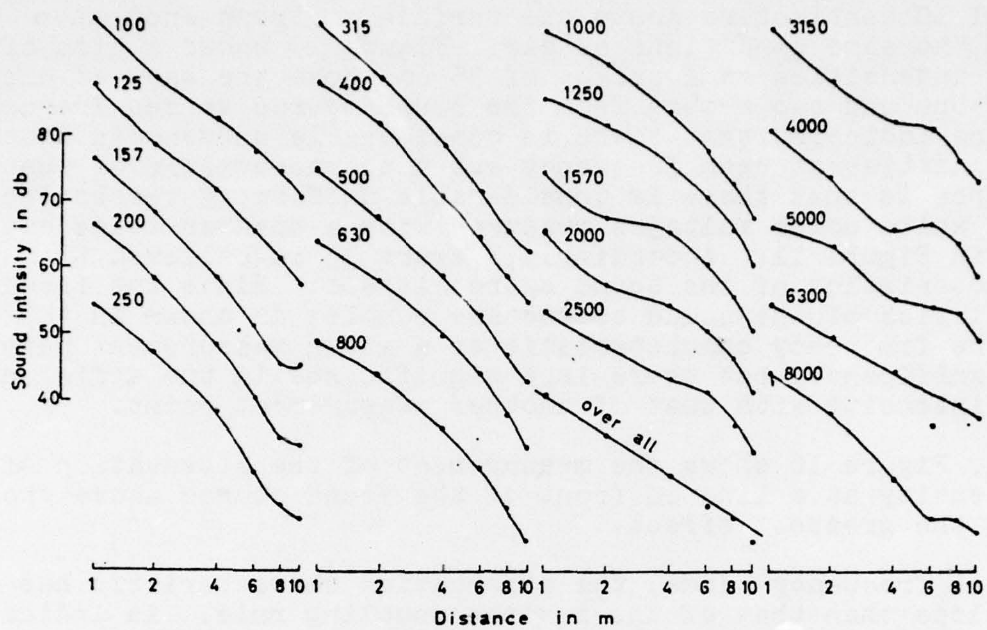

Figure 14. Relation of distance from sound source and sound intensity at speaker axis line at height of 35 cm above snow.

From measurement of the sound impedance of snow samples, the fact that the sound pattern for fresh snow is believed to be a collection of many resonances was already indicated [4] and this is supported by the perpendicular distribution of the sound site above fresh snow.

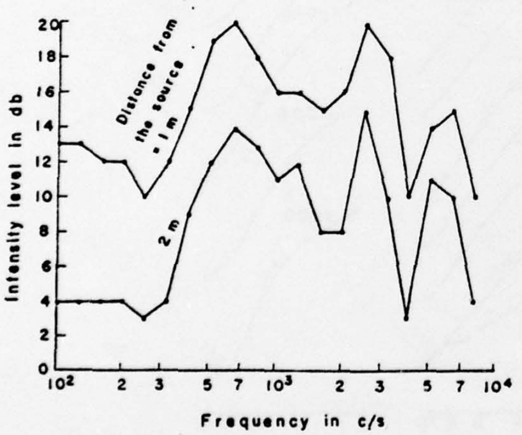

Figure 15. Sound intensity at height of 35 cm above snow at distances of one and two meters from the sound source.

It seems from the perpendicular distribution of the sound site that there is virtually no effect of the snow surface above heights of 20 cm, but on the axis of the speaker, specifically at heights of 35 cm above the snow, how does the sound attenuate with distance from the snow source? Figure 14 shows those results. In the air or in an anechoic room, the sound intensity ought to diminish in inverse proportion to doubling of the distance from the sound source, a so-called inverse doubling rule ought to be in effect. In Figure 14, the entire characteristic of white noise is on the straight line of the inverse doubling rule and even at

each frequency band, attenuation occurs at virtually the same angle as that of the inverse doubling rule. This indicates that heights of several 10 centimeters above the surface of fresh snow have virtually the same conditions as air. Figure 15 shows a plot of the sound intensities at a height of 35 cm above the snow at distances of one and two meters from the sound source versus frequency. This figure indicates that there is considerable unevenness in the sound intensities at each frequency but a characteristic of the sound source is that there is considerable uniformity versus frequency at white noise voltages measured with a speaker voice coil as shown in Figure 12. Accordingly, Figure 15 is believed to express the characteristics of the sound source itself. Since the frequency characteristics of the sound source are complex as shown in the figure, the frequency characteristic at a given measurement point has no significance, but there is a significance in the difference of sound intensity with that of another measurement point.

Next, Figure 16 shows the measurement of the attenuation of sound intensity at a line in front of the sound source above snow which has the greatest effect.

At all frequency bands, the attenuation characteristic has a greater slope than that of the inverse doubling rule. As indicated in Figure 11, since the sound wave expands as a virtually spherical wave from the sound source, if the sound pressure at the snow surface 1 meter in front of this sound source is taken as p_1, the sound

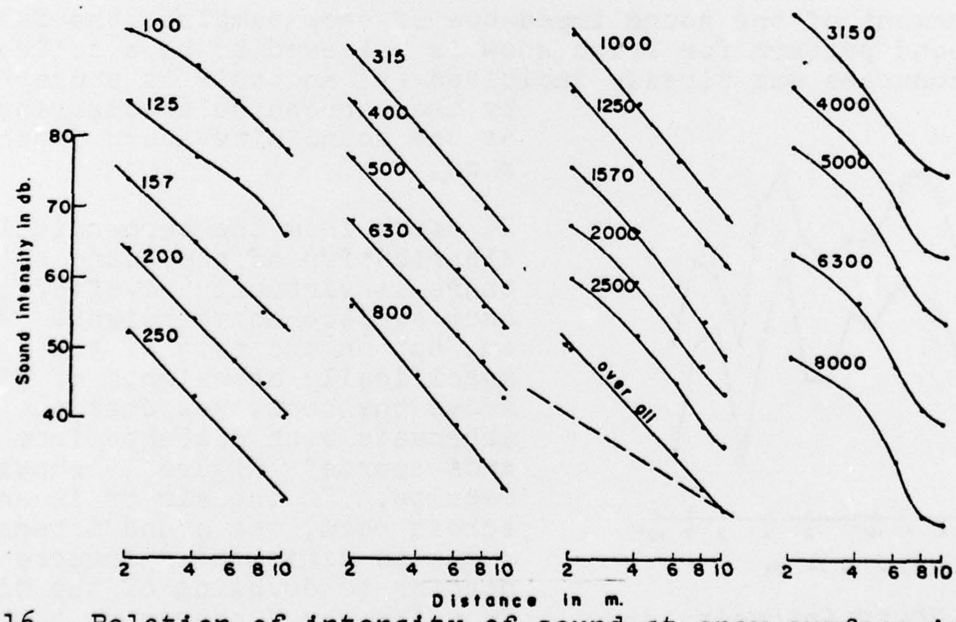

Figure 16. Relation of intensity of sound at snow surface in front of the sound source and the distance from the sound source. Broken line is the inverse doubling rule.

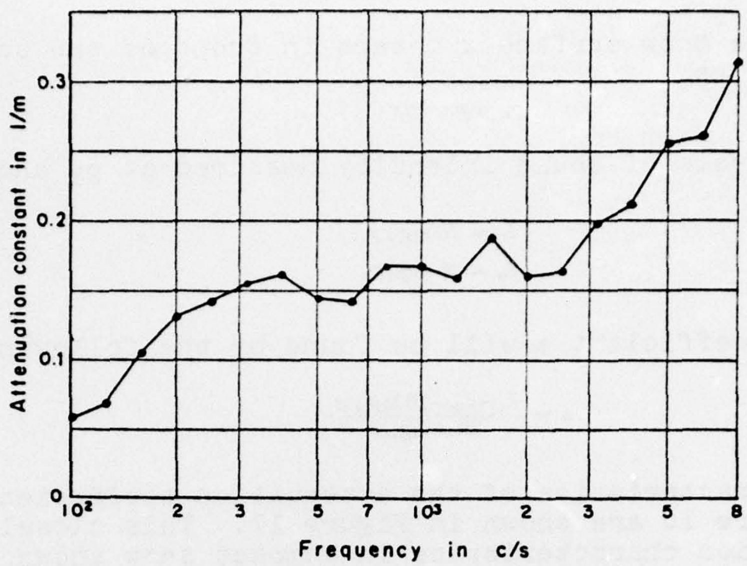

Figure 17. Frequency characteristic of attenuation coefficient at the surface of new snow.

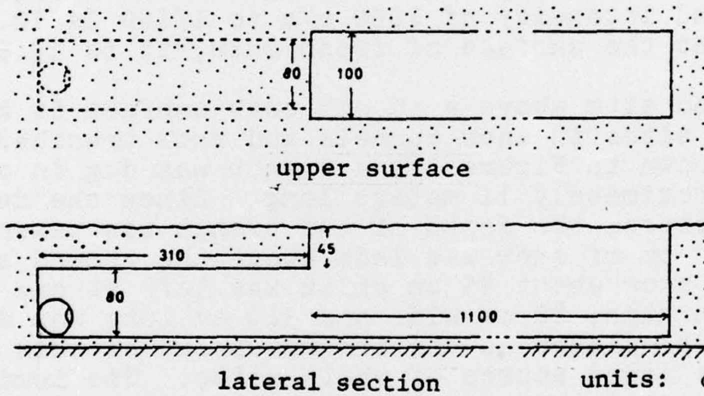

Figure 18. A rough sketch of the snow tunnel and snow trench.

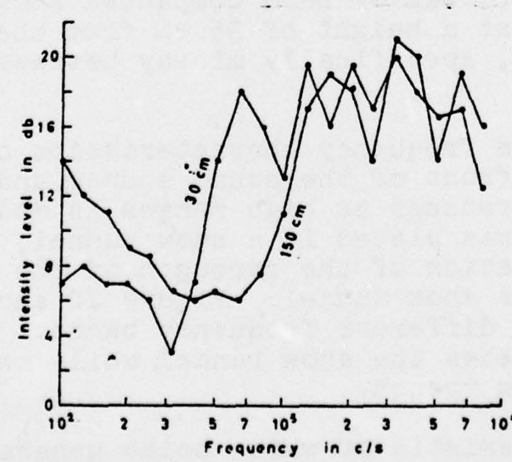

Figure 19. Frequency characteristics of white noise within snow tunnel.

pressure p_x at the snow surface x meters in front of the sound source will be expressed as

$$p_x = p_1 e^{-\alpha x}/x \tag{7}$$

If we take the levels of sound intensity measured at p_1 and p_x respectively as

$$L_1 = 20 \log_{10} p_1 \tag{8}$$
$$L_x = 20 \log_{10} p_x$$

the attenuation coefficient α will be found by the following formula from formula (8)

$$\alpha = \frac{L_1 - L_x - 20 \log_{10} x}{20\, x \log_{10} e} \tag{9}$$

The frequency characteristics of the attenuation coefficient calculated from Figure 16 are shown in Figure 17. This closely resembles the attenuation characteristics in compact snow shown in Figure 6 but, while the size of the values is shown in 1/cm units in Figure 6, the units in Figure 17 are 1/m so that the attenuation above snow is approximately 1/100 times smaller than the attenuation in compact snow. Specifically, one example is that the distance required for attenuation of sound intensity of 1000 c/s to 1/100 is 12.5 cm for compact snow, but at the surface of fresh snow, it is 13.5 m.

Since the sound site above a smooth snow surface is known, a study of the sound sites in snow tunnels and snow trenches follows. Specifically, as shown in Figure 18, a trench was dug in snow one meter wide and approximately 11 meters long. Since the depth of the snow was 1.5 meters, the depth of the trench was taken as 1.4 meters and about 10 cm of snow was left above the ground surface. Next, a ceiling of snow about 45 cm thick was left at one side and a snow tunnel 80 cm high, 80 cm wide and 310 cm long was dug. A spherical speaker was placed at the innermost end of this tunnel and was used as the sound source of white noise. The densities of the walls of the snow tunnel and snow trench were 0.30 - 0.45 and the bottom of the snow trench was of hard compacted snow. The sound intensity was measured at a height of 35 cm from the floor along the axis of the speaker, specifically midway between the left and right snow walls.

Figure 19 shows the frequency characteristics of sound intensity at 30 cm and 150 cm in front of the sound source, and in comparison with Figure 15, the unevenness at high ranges is moderated somewhat. Since the sound source was placed in a snow tunnel, this is believed to be due to an equalization of the strength of the sound due to reverberation within the snow tunnel. Figure 20 shows the attenuation characteristics at different frequency bands. The side to the left of the arrow indicates the snow tunnel, while the side to the right indicates the snow trench.

The entire characteristic of white noise generally follows the inverse doubling rule, but at positions near the sound source and distant from the sound source, more moderate curves than those of

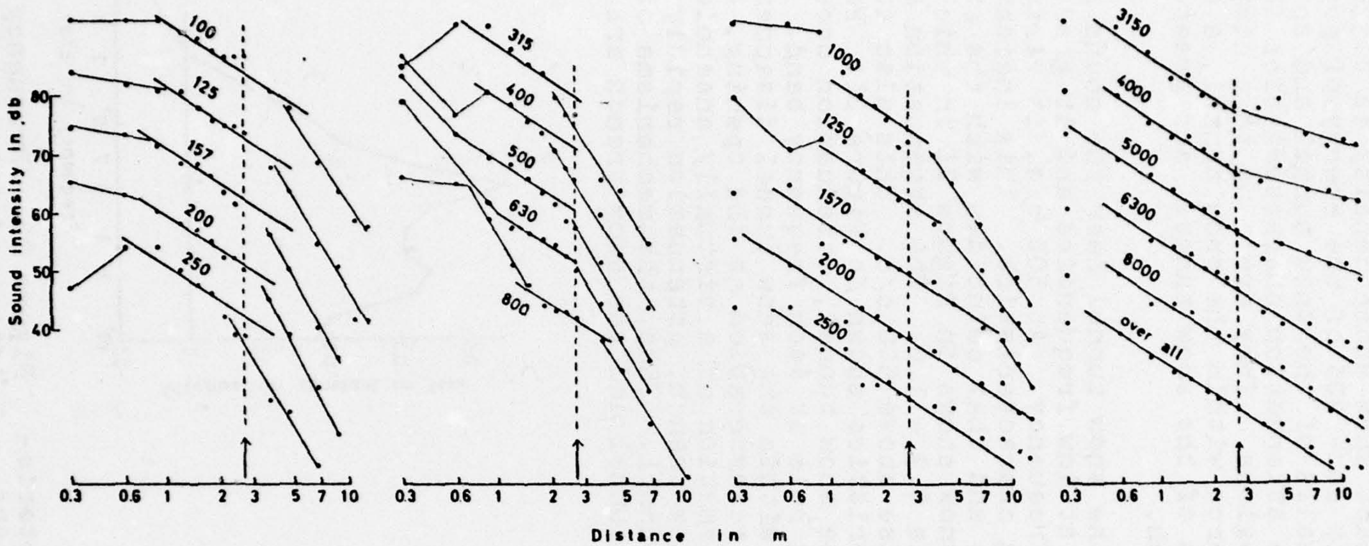

Figure 20. Attenuation characteristics in snow tunnel and snow trench. Arrows indicate the position of the mouth of the snow tunnel. The left side is the snow tunnel and the right side is the snow trench. The thick line drawn at each frequency band indicates the inverse doubling rule.

the inverse doubling rule form. At a position near the sound source, this indicates reverberation within the snow tunnel, while at distant positions, this indicates reverberation of the snow wall of the trench relative to the sound source. Because the absorption rate of a 10 cm thick sample of compact snow whose density is 0.33 - 0.37 is 0.8 - 0.6 [5] m, approximately 20 - 40% of the energy of projected sound is reflected off the walls of the snow tunnel and snow trench. It is possible to divide the attenuation characteristics for each frequency band into three regions. They are: up to a distance of one meter from the sound source within the snow tunnel, a distance of 1-2.7 meters to the mouth of the snow tunnel, and greater distances within the snow trench.

For the first, within the snow tunnel near the sound source, the attenuation is very low at low frequencies and it gradually increases with increase in frequency. At 500 c/s, it virtually follows the inverse doubling characteristics. This indicates that at 500 c/s, there is no echo and that coincides with the absorption characteristics of compact snow shown in Figure 21 in which the absorption rate at 500 c/s is 0.9 - 1.0. The attenuation again gradually diminishes with rise above 500 c/s. This also coincides with the absorption characteristics shown in Figure 21. For the second, near the mouth of the snow tunnel, attenuation occurs which follows the inverse doubling rule at each frequency band. Since reverberations off the walls within the snow tunnel disappear and since there is virtually no reverberation at the opening, this is believed to be due to the formation of a virtually anechoic room. For the third, within the snow trench, attenuation rapidly increases from the mouth of the snow tunnel. Thus, the mechanisms of sound attenuation within the snow tunnel and the snow trench are believed

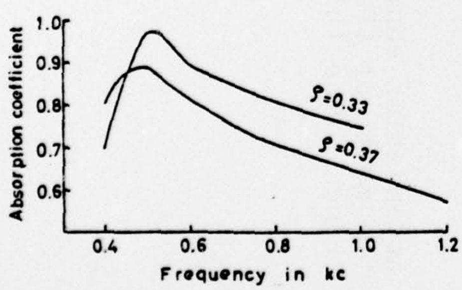

Figure 21. Absorption characteristics of compact snow of 0.33 and 0.37 density.

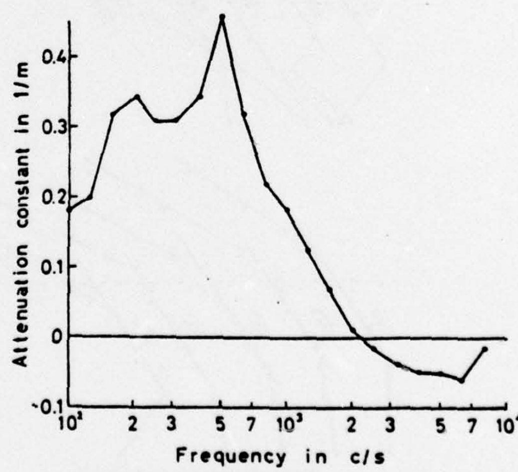

Figure 22. Frequency characteristics of attenuation coefficient in snow trench.

to differ and the site of the assumed sound source projected within the snow trench is taken as the mouth of the snow tunnel. Accordingly, since the size of the sound source is tentatively taken as the 80 x 80 cm mouth of the snow tunnel, there is a problem in comparison with the inverse doubling rule for a point sound source in free air, but calculation of the attenuation coefficient for each frequency band was made in the same manner as previously and the results are shown in Figure 22. This tendency is that seen in the absorption characteristics of Figure 21. The fact that the attenuation coefficient becomes negative at high ranges in excess of 2 KC indicates that the attenuation coefficient characteristics have a slope smaller than that of the inverse doubling rule. This indicates that there is a reverberation effect from the walls of the edge of the snow trench, because the absorption rate is low at high sound regions.

IV. CONCLUSION

Using white noise, the transmission loss of fallen snow samples was measured. The attenuation coefficient of sound within fallen snow was measured from this. In addition, the sound sites of a level, fresh snow surface and of a compact snow tunnel and snow trench were studied and the attenuation coefficients at these snow surfaces were found. The frequency characteristics of the attenuation coefficient of a fallen snow sample and a snow surface had the same tendencies as the sound absorption characteristics of the samples. In addition, we found that the attenuation at a fresh snow surface was about 1/100 that of the attenuation within a sample of compact snow. We believe these samples will serve as references for acoustic design in snow regions and the TL characteristics of fallen snow samples have a close relation to the structure. We anticipate that this will serve as an indicator of the structure of fallen snow.

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